Climate and Transport

Weather and Climate Change Impacts on Transportation Systems

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Climate and Transport

“Weather affects the operation of the transportation systems that we all rely on…. Climate, on the other hand, affects transportation infrastructure.” McGuirk, WMO
Climate and Transport

“Work to protect life and property, promote safe and efficient commerce, and improve safety and mobility with timely transportation-relevant weather information.” NOAA & FHWY
Sources:

Weather Information for Surface Transportation – Office of the Federal Coordinator for Meteorology - 2002

The Potential Impacts of Climate Change on U.S. Transportation – Transportation Research Board, March 2008

Peterson, Thomas C., M. McGuirk et. al., Climate Variability and Change with Implications for Transportation, National Research Council TRB, March 2008


Photos: David McGuirk
1. **What does the science say?**
   Adverse weather affects transport

2. **Why is it important?**
   Climate analysis shows where and when safety is risky and costs are high

3. **What does it mean for our future?**
   Climate change adaptation is necessary for every mode
1. Weather affects transport
Parameters - visibility, freezing rain, snow, heavy precipitation, temperature extremes, extreme weather, wind

2. Climate analysis - where and when
Frequency analysis, rush hours, wind roses, coastal building design criteria

3. Climate change adaptation
Rail
Airports
Pipelines
Ports and Waterways
Highways and Transit
1. WEATHER AFFECTS TRANSPORT
Airports

[MSP] MINNEAPOLIS
Windrose Plot [All Year]
Period of Record: 01 Jan 2014 - 31 Jan 2014
Obs Count: 1000 Calm; 4.2% Avg Speed: 10.8 mph

Ceiling-visibility-wind rose, density altitude – runway design
Dep & Arv weather frequency, Sea Level
Significant impacts of adverse weather annually on the Nation's roads

Annual average 2005-2014 highways
1.3 million crashes
450,000 injuries
5,000 fatalities

Sources:
Federal Highway Department
http://www.ops.fhwa.dot.gov/weather/q1_roadimpact.htm

NOAA U.S. Natural Hazard Statistics Storm Data Asheville, NC
http://www.nws.noaa.gov/om/hazstats.shtml

$42 billion in annual economic loss from these weather-related crashes (deaths, injuries, and property) Lombardo, L. 2000. Overview of US Crashes and Environment. Presentation at the WIST II Forum, December 4-6, 2000.).

Weather-related traffic delays on highways costs the freight industry $8 billion to $9 billion annually (FHWY Cambridge 2016)
<table>
<thead>
<tr>
<th>Weather Variables</th>
<th>Roadway Impacts</th>
<th>Trafficflow Impacts</th>
<th>Operational Impacts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air temperature and humidity</td>
<td>N/A</td>
<td>N/A</td>
<td>• Road treatment strategy (e.g., snow and ice control)</td>
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<tr>
<td>Wind speed</td>
<td>• Visibility distance (due to blowing snow, dust) • Lane obstruction (due to wind-blown snow, debris)</td>
<td>• Traffic speed • Travel time delay • Accident: risk</td>
<td>• Vehicle performance (e.g., stability) • Access control (e.g., restrict vehicle type, close road) • Evacuation decision support</td>
</tr>
<tr>
<td>Precipitation (type, rate, start &amp; end times)</td>
<td>• Visibility distance • Pavement friction • Lane obstruction</td>
<td>• Roadway capacity • Traffic speed • Travel time delay • Accident: risk</td>
<td>• Vehicle performance (e.g., traction) • Driver capabilities/behavior • Road treatment strategy • Traffic signal timing • Speed limit control • Evacuation decision support • Institutional coordination</td>
</tr>
<tr>
<td>Fog</td>
<td>• Visibility distance</td>
<td>• Traffic speed • Speed variance • Travel time delay • Accident: risk</td>
<td>• Driver capabilities/behavior • Road treatment strategy • Access control • Speed limit control</td>
</tr>
<tr>
<td>Pavement temperature</td>
<td>• Infrastructure damage</td>
<td>N/A</td>
<td>• Road treatment strategy</td>
</tr>
<tr>
<td>Pavement condition</td>
<td>• Pavement friction • Infrastructure damage</td>
<td>• Roadway capacity • Traffic speed • Travel time delay • Accident: risk</td>
<td>• Vehicle performance • Driver capabilities/behavior (e.g., route choice) • Road treatment strategy • Traffic signal timing • Speed limit control</td>
</tr>
<tr>
<td>Water level</td>
<td>• Lane submersion</td>
<td>• Traffic speed • Travel time delay • Accident: risk</td>
<td>• Access control • Evacuation decision support • Institutional coordination</td>
</tr>
</tbody>
</table>

Source: OFCM Weather Information for Surface Transportation
Blowing Snow

High winds caused low visibility in Glacier National Park
Saint Mary Montana webcam
**Measure, Model, & Monitor**

**Sensors** report dew point, humidity, air temperature and wind velocity, pavement temperatures, amount of anti-icing chemicals present, friction measurements installed in vehicles.

**Models** predict the start of ice formation on pavements, suggest anti-icing treatment, type, amount, when to apply, speed reduction for visibility, wet pavement conditions.

Roadway Weather Info System

KY-DOT traffic operation center
Road Way Information System

- Reports dew point, humidity, air temperature and wind velocity and direction
- Pavement sensors monitor
  - pavement temperatures
  - amount of anti-icing chemicals currently present
- Friction measurements
  - friction instruments installed in a vehicle - help to determine whether and when more chemical needs to be applied.
- Information recorded and fed into a central database,
- Models predict the start of ice formation on pavements
- Suggest anti-icing treatment, other transportation applications
  - type, amount, when to apply
  - Visibility reduction, wet pavement speed reduction

MesoWest stations

RWIS stations

Union Pacific Railroad stations
1. What does the science say?
   Adverse weather affects transport
2. CLIMATE ANALYSIS
Climate Analysis

• Calculate long-term averages
• Climatology - diurnal & seasonal & regional places
• Analysis for operational thresholds
  – Heavy Precipitation by Time of Day
  – Visibility by Time of Day
  – Storm Data – frequency of storms by locality
  – Distribution of rain, hail, snow, freezing rain
• Concentrate on design criteria
  – NOAA frequency duration intensity design criteria
  – 100-year return period 5-24-hour rainfall duration intensity curves used for water flow design criteria
  – Frost-freeze periods
  – Other
Where & when safety is risky

Climatology of fog, snow, rain
By time-of-day, location,
Compare to traffic, vehicle miles traveled
Compare city peak hour weather
Visibility

Seattle, WA
1948-2005

Atlanta, GA
Visibility
1945-2005

Visibility less than ¼ mile happens most often at peak traffic flow 7am
Where & when safety is risky and costs are high

Truck-freight weather-impact cost study area 13 regions 2000-2014

- Selected weather stations at airports
  - sufficient length of record
  - inventory 5 years of data within the period

- Frequency of occurrence of weather events
  - fog, drizzle, rain, snow, sleet, hail, gusts
  - by hour of day and month

- Highway freight traffic
  - by roadway segment
  - freight value

- Storm Data Inventory database
  - Severe weather by county
  - Quantitative correlation with truck traffic
  - Analysis of slower speeds due to adverse weather
  - Qualitative analysis of storms that stopped traffic altogether (closed freeway)
  - verified by State Climate Offices
## Frequency of weather by day

Select a variety of climate for analysis

<table>
<thead>
<tr>
<th></th>
<th>Seattle</th>
<th>Pittsburgh</th>
<th>Louisville</th>
<th>Chicago</th>
<th>Newark</th>
<th>Rapid City</th>
<th>Raleigh</th>
<th>Oklahoma City</th>
<th>Denver</th>
<th>Phoenix</th>
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<tr>
<td>#days</td>
<td></td>
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<tr>
<td>Cloudy</td>
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<td>174</td>
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<td>157</td>
<td>149</td>
<td>68</td>
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<tr>
<td>Snow*</td>
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<td>13</td>
<td>15</td>
<td>26</td>
<td>14</td>
<td>36</td>
<td>4</td>
<td>5</td>
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<td>0</td>
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<td>25</td>
<td>1</td>
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<tr>
<td>Tstorm</td>
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<td>36</td>
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<td>38</td>
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<td>33</td>
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<td>Rain&gt;1.0</td>
<td>5</td>
<td>6</td>
<td>11</td>
<td>8</td>
<td>12</td>
<td>2</td>
<td>10</td>
<td>11</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Rain&gt;.01</td>
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<td>152</td>
<td>130</td>
<td>124</td>
<td>122</td>
<td>94</td>
<td>114</td>
<td>84</td>
<td>80</td>
<td>36</td>
</tr>
</tbody>
</table>

Average number of Days per Year with weather.

Source: Extracted from report of Task 2.1 “Investigate Potential Sources of Weather Data”. Data source NOAA, *Average number of days with snow calculated separately from daily Cooperative Station Data for three seasons 2011-2013
Five-year summation of the frequency of all-weather types for each location. The higher the number is, the greater the percentage of inclement weather. Inclement weather appears to be overall more frequent in the winter months than the summer months (because we are counting more winter weather types than summer weather).

(Source: McGuirk and Burnet, 2016)
Frequency of weather by hour 13 localities

Frequency of Weather
Percentage of hours with weather %

- Atlanta
- Chicago
- Columbus
- Denver
- Lexington
- Newark
- Oklahoma City
- Phoenix
- Pittsburgh
- Raleigh
- Rapid City
- Reno
- Seattle

- gust>30
- rain
- drizzle
- fog
- snow
- sleet
- hail
- dust/etc
Dust Storm

Low frequency, high impact

Massive dust over northern Oklahoma triggered a multi-vehicle accident on I-35 with nearly three dozen vehicles and tractor-trailers involved (AP)

Dust storm in eastern WA on August 12, 2014 (USA Today) Photo taken by Chad Devine.
Time of day & weekends matter

Average speed by hour under no-weather conditions.

Traffic volumes - adjusted FAF – using Transportation Economics’ research

(Source: FHWY, 2016, Noel Perry, Cambridge Systematics)
Rain occurs more frequently in day than night in the study area. (Source: McGuirk and Burnet, 2016)
“Ice and Snow weather events account for over half of all lost time due to decreased traffic speeds and are the most costly for the freight industry (costing over 25 dollars per segment hour and over 25 cents per truck per segment).”

(Source: FHWY, 2016, Noel Perry, Cambridge Systematics)

No significance in day vs night % hours with snow climatology for February.
(Source: McGuirk and Burnet, 2016)
Winds daylight vs night

Places with most gusty winds

Comparison of the % hours with wind gust >30mph climatology for April.
(Source: McGuirk and Burnet, 2016)
Winds daylight vs night

March wind gusts > 20, 25, 30 mph

(Source: McGuirk and Burnet, 2016)

Oklahoma City, OK

(Source: McGuirk and Burnet, 2016)
Rain morning vs evening rush hours

Places with most rainy hours

A comparison of the % hours with Rain climatology for April
(Source: McGuirk and Burnet, 2016)
Rain morning vs evening rush hours

Places with most rainy hours

A comparison of the % hours with Rain climatology for April
(Source: McGuirk and Burnet, 2016)
“Time-of-day matters—all highways suffer more in terms of loss of speed for weather events that occur in the morning and evening rush hour periods.”

(Source: FHWY, 2016, Noel Perry, Cambridge Systematics)
Atlanta – all weather frequency March

Airport locations

Source: McGuirk and Burnet, 2016
The National Performance Management Research Data Set (NPMRDS) data on average travel times for freight vehicles along the National Highway System (NHS) and FHWA’s Freight Analysis Framework Version 3.5 (FAF3.5), estimates for tonnage, value, and domestic ton-miles by region of origin and destination.
Number of weather events by type across all 13 study areas 2000-2014.

(Source: FHWY, 2016, Noel Perry, Cambridge Systematics
Data Source NOAA Storm Events Database)
Change in speed from previous hour for all analyzed weather events in Atlanta, Georgia.
(Source: FHWY, 2016, Noel Perry, Cambridge Systematics)
Effects of different weather events over time in Atlanta, Georgia.
(Source: FHWA, 2016, Noel Perry, Cambridge Systematics)
Truck & storm data

Weather Effect – Change In MPH – Last Hour
(+4)

MPH
-9 -8 -7 -6 -5 -4 -3 -2 -1 0 1

Fire Flood Fog Ice & Snow Rain Temperature Wind

Average of Change From Average Non Storm

“Weather-related traffic delay costs the freight industry $8 billion to $9 billion annually. By examining 13 regions in the United States that vary in terms of their weather, population size, and economies, this report demonstrates how these national trends impact individual regions.”

(Source: FHWY, 2016, Noel Perry, Cambridge Systematics)
2. Why is it important?

Climate analysis shows where and when safety is risky and costs are high
3. CLIMATE CHANGE
Climate change impacts


Methodology

- Historical Analysis of local Extremes
- IPCC Model region’s projections of mean temperature and precipitation
- Model derived indices of extremes
- Reanalyzed probability of future local extremes
- Used thresholds for transport operations from WIST

(Source: Peterson)
Climate Change Transport Modes

Rail
Airports
Pipelines
Ports and Waterways
Highways and Transit
Climate Change Impacts

More hot temperatures
   Exceed threshold for maintenance, Rail-way buckling, road rutting,
   Lowering of Great Lakes, opening NW passage
   Higher elevation airports exceeding load limits with high density altitude

Fewer below freezing days
   Longer freeze-thaw season – spring load
   Permafrost thaw, load limits ice roads, limits on forest service roads

More storminess
   Infrastructure damage from lightning, winds, hail
   Road and rail washouts from more intense precipitation, exceeding design specifications, riverine flooding

Sea Level Rise Storm Surge  shoreline retreat
   ports, docks, intermodal transport effected

Tropical cyclones climatology
   Evacuation plans vs shelter in place

(Source: Peterson)
Transportation

Key Messages:

- Sea-level rise and storm surge will increase the risk of major coastal impacts, including both temporary and permanent flooding of airports, roads, rail lines, and tunnels.
- Flooding from increasingly intense downpours will increase the risk of disruptions and delays in air, rail, and road transportation, and damage from mudslides in some areas.
- The increase in extreme heat will limit some transportation operations and cause pavement and track damage. Decreased extreme cold will provide some benefits such as reduced snow and ice removal costs.
- Increased intensity of strong hurricanes would lead to more evacuations, infrastructure damage and failure, and transportation interruptions.
- Arctic warming will continue to reduce sea ice, lengthening the ocean transport season, but also resulting in greater coastal erosion due to waves. Permafrost thaw in Alaska will damage infrastructure. The ice road season will become shorter.
Increasing heavy rain events

– Delays in many forms of transportation
– Localized flooding coastal and riverine

• Damage to bridges designed to last 100 years
• Scouring of pipeline roadbeds

Flooding inland

Source: nowcowx.com

Major flooding along I-10 in AZ at 43rd Avenue
(ADOT Traffic Operations Center)
Temperature: Climate

• General warming would contribute to:
  – Melting Arctic sea ice Potential opening of NW passage
  – Thawing permafrost creates problems for Alaskan roads and pipeline
  – Decreased use of ice roads and frozen rural roads

• More very hot weather
  – Railroad track and roadway buckling
  – Airplane runway take-off roll distance increases
  – Bridges subject to extra stresses through thermal expansion and increased movement.

Sources: Peterson, Stratus
Conclusions

• “Transportation is definitely sensitive to climate change.
• Winners and losers
• The system was built for historical weather and climate
• Planners look to the future
  – Roadway 25 years
  – Railroad 50 years
  – Bridges and underpasses 100 years
• New infrastructure should take climate projections into consideration as well
  – E.g., there are options for laying railroad tracks that have different temperature thresholds for buckling.”

3. What does it mean for our future?

Climate change adaptation is necessary for every Mode of transport
Questions?
Climate and Transport

Citation:
McGuirk, Marjorie, Weather and Climate Change Impacts on Transportation Systems,
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Thank you!

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